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T. C. MENDENHALL
SUPERINTENDENT

GEODESY

ON THE VARIATIONS OF LATITUDE

AND ON DETERMINATIONS OF GRAVITY

AND THE MAGNETIC ELEMENTS

AT STATIONS IN THE

HAWAIIAN ISLANDS

A preliminary Report by E. D. PRESTON, Assistant

APPENDIX No. 13—REPORT FOR 1891

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APPENDIX No. 13.—1891.

ON OBSERVATIONS FOR THE VARIATIONS OF LATITUDE MADE NEAR HONOLULU, OAHU, HAWAIIAN ISLANDS, IN COÖPERATION WITH THE WORK OF THE INTERNATIONAL GEODETIC ASSOCIATION, AND ON DETERMINATIONS OF GRAVITY AND THE MAGNETIC ELEMENTS.

A preliminary report by E. D. PRESTON, Assistant.

Submitted for publication January 17, 1893.

This preliminary report will include notices of—

I. The international latitude observations from June 6, 1891, to June 25, 1892.
II. The measurements of the force of gravity on Oahu and Hawaii from June 9, 1891, to July 25, 1892.
III. The determination of the magnetic elements made at intervals from August 11, 1891, to September 9, 1892.
IV. Meteorological observations, including barometric determination of heights of Mauna Kea, from July 1, 1892, to July 27, 1892.

I.—OBSERVATIONS FOR THE VARIATIONS OF LATITUDE.

The following are the circumstances that led to this work: Some latitude observations made in Germany, at Berlin and Potsdam, and at Prague in Bohemia, showed a progressive yearly change in the results. As the motion was in the same direction for all three places, it became desirable to make a further study of the movement by observing at stations differing greatly in longitude; for if there had been a real motion of the pole, the effect on terrestrial latitudes would be in opposite directions on different sides of the earth. In order, therefore, to bring out the law of change most advantageously the International Geodetic Association took the matter up and proposed to send an observer to the Hawaiian Islands to make latitude determinations simultaneously with those executed in Europe. The difference of longitude of Berlin and Honolulu is $11^h 25^m$. The United States Government was asked to coöperate in order that the result of work, whatever it might be, should be checked independently by another observer and another instrument. This led to my assignment by the Superintendent of the Coast and Geodetic Survey, with instructions for some additional gravity, latitude, and magnetic observations during my stay in the islands.

I left Washington on April 18, 1891, in company with Dr. Marcuse, the European representative of the International Geodetic Association, arriving at Honolulu on the 8th of May, in the afternoon. Having been directed by the Superintendent to observe the Transit of Mercury, which took place on the 9th, provided we should arrive in time, the instruments were passed through the custom-house on the day of landing; the same evening the station was selected at Waikiki, 3 miles southeast of Honolulu, and the transit was successfully observed the following day.* Our next occupation was to choose a permanent site for the astronomical work. After several disappointments, the observatories were finally located on the property of Mr. J. F. Brown, of the Government Survey, who generously gave the use of the ground during the year.

Waikiki was preferred in order to avoid the clouds of Honolulu, as my experience there in 1883 and 1887 showed that place to be very unfavorable for continuous star observations. There were numerous unavoidable delays in getting material and workmen, and, as the programme was to begin work as soon after May 15 as possible, it was decided to concentrate all the force on one building and let one observer begin immediately. As I had several more instruments to set up than my colleague, it was deemed advisable for him to begin first; so that my observatory was not finished until five days after his. He began observations on June 1; my first ones were made on June 6. From this date on, the plan of work adopted was continuously carried out. Latitude observations were made in connection with Dr. Marcuse. Time was determined for the gravity work in the intervals between pairs of stars, and the pendulum was swung during the entire evening, coincidences being noted at the beginning and end of the night's work, and whenever opportunity offered during the latitude and time observations. This gives a determination of gravity corresponding to each latitude determination, and will help to decide the question whether the change of latitude comes from a real motion of the pole or from transfers of large bodies of matter under the surface of the earth.

From June 6, 1891, to June 25, 1892, there were made 2 434 determinations of latitude; observations being made on 220 nights, as follows:

	Nights.	Latitudes.		Nights.	Latitudes.
1891			1892		
June,	20	212	January,	18	195
July,	14	156	February,	19	267
August,	20	254	March,	18	215
September,	11	155	April,	16	122
October,	11	124	May,	23	219
November,	15	169	June,	16	127
December,	19	219			
				220	2 434

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* See a report of these observations in Appendix No. 12, 1891.

II.—GRAVITY DETERMINATIONS.

Before leaving for Honolulu I suggested to the Superintendent the feasibility of making continuous observations for the force of gravity. This was possible without increasing the expense of the work, and such observations were made at Waikiki every night that latitudes were observed. We thus have a series of nearly 200 nights of gravity determinations extending throughout the year. Time stars were observed before the first coincidence and after the last one, and as many observations as possible were made on the pendulum at intervals between the latitude pairs, so that in all there are not far from 1 000 measures of the force of gravity.

On June 15 the pendulum apparatus was taken down at Waikiki and mounted at Honolulu. As I desired to continue the latitude work at the former place as long as possible, the zenith telescope was left standing and the latitudes were continued on every clear night while preparing the stations in Honolulu. After the pendulum observations were in operation the Waikiki work was still carried on whenever possible to observe stars. The pendulum was observed during the day at Honolulu and stars obtained during the early evening. Then the trip was made to Waikiki (3 miles), and latitude continued until the end of the list.

On June 28 we left for Hawaii, the party consisting of Prof. W. D. Alexander, the Surveyor-general, Mr. W. E. Wall, Mr. W. W. Chamberlain, Mr. Louis Koch, and myself. At Waimea the party was joined by Mr. J. M. Muir, a volunteer observer, who rendered valuable service on the mountain both in triangulation and magnetic work.

The object of this trip was the determination of the force of gravity at the base and summit of Mauna Kea, the highest peak on the islands. The elevation is nearly 14 000 feet. Other observations were also made consisting of latitude, magnetic, meteorological, etc.

Landing at Kawaihae on the evening of June 29, this station was occupied before July 7. Observations were made for latitude, time, gravity, and magnetism.

From this point we passed to the plains of Waimea at an elevation of 2 600 feet. At this place animals were engaged for the ascent and packers hired. While making the necessary arrangements, two stations were occupied for magnetic observations. One of these had been occupied in 1872 by the Government Survey officers and the other was a new station at the end of their base line. This work was done at the request of the Surveyor-general.

On July 12 the party left for Kalaieha. The ascent is very gradual. The trail winds around the mountain, and after a journey of 35 miles we found ourselves at an elevation of 6 700 feet above the sea. From this point to the summit the path is rough and steep. Only 12 miles more travel were necessary to overcome the same vertical distance that we had risen in traveling the 50 previous miles. A full series of observations was made at Kalaieha, but as this point lies just at the beginning of the cloud region the greatest difficulty was experienced in getting stars.

Only five pairs could be secured for latitude and the time determinations for gravity are rather weak. Much of the work was done during rain. The object glass was uncovered long enough to make the observation while the star was passing, and immediately after a pair was observed or after a half set for time the telescope was carried into the tent to be wiped and dried. Owing to the great difficulty of transporting baggage, no separate observatory tent was taken and the telescope was mounted in the open air.

At this point the party was reinforced by Mr. E. D. Baldwin, of the Government Survey, who had come up on the windward side, bringing some pack mules and a guide from Hilo.

We began the ascent from Kalaieha on July 19, with a pack train of twenty-two animals and eleven men. One of the donkeys that carried the magnetic instruments and some firewood became unruly and ran away. As we were enveloped in fog, he found no difficulty in escaping, and was only recaptured at 3:30 p. m., after eight hours' hunting by eight of the party. This necessarily deferred the trip one day, and another start was made at 7:40 the following morning.

We arrived at Waiau, over 13 000 feet elevation, late in the afternoon. About half the party made the ascent by 3 p. m., but as many of the animals were suffering from the rarity of the air and from the travel over the rough lava, it was impossible to urge them much, and many did not arrive until late; in fact, some did not get up at all, and from sheer exhaustion refused to go beyond about 12 000 feet. They were unloaded, and their loads taken by stronger mules that had already been to the top and unloaded.

A stay of five days and six nights was made at Waiau. The ranges of temperature were from 13° F. at night to 108° at noonday, the thermometer being in the same position for both readings.

The pack animals arrived from below at 11 a. m. of July 26. Everything was in readiness, and after two and one-half hours spent in packing the mules we started down. On the way we passed by Lilinoe, where in past times the natives had established a burial ground at an elevation of about 12 500 feet, and farther on we came to Keanakakoi (the ax-makers' cave), where before the introduction of iron a quarry had been opened for the production of battle-axes. The elevation of this point is over 12 000 feet.

We arrived at Kalaieha the same evening. Two days were passed here, repacking the instruments and putting the records in order. All the luggage was sent down the lee side of the island to Kawaihae, a distance of 50 miles, to be shipped to Honolulu. As it was desired to make magnetic observations at Hilo, Mr. Baldwin, Mr. Wall, and myself left the party here. This could be done without increasing the time spent on the island, as we were able to take the same steamer that was to pass round the island and load the instruments at Kawaihae.

III.—MAGNETIC OBSERVATIONS.

The first of these were made on August 11, 1891, when engaged in the latitude observations at Waikiki. The date of occupation of this station was chosen so that all the work could go on together. At the time mentioned our astronomical observations extended from 7 p. m. to 11 p. m. With these hours for night work it was possible to make magnetic observations for all three elements during the day and allow no break to occur in the regular series for time, latitude, and gravity in the evening.

The second station was made at Kahuku, on the extreme north point of Oahu. This made it necessary for me to be absent from Waikiki from November 24 to November 29. Leaving Waikiki at 6 a. m. of the 24th, the distance to Waialua was made by 3 p. m., where lunch was taken. In the evening the remainder of the trip was made, and we arrived at Kahuku at 8 p. m., having ridden horseback more than 40 miles over a difficult road. On the following morning, November 25, observations were begun. They were completed on the 27th, and we were back in Honolulu on the evening of the 28th. Prof. Alexander accompanied me and kindly recorded these observations.

Honolulu was occupied on June 2, 3, and 4, 1892, at the same time that the Waikiki work was in progress. The subsequent magnetic stations, up to the time of the conclusion of the Mauna Kea work, were occupied in connection with gravity and latitude observations, and have already been described.

We arrived at Hilo on the evening of July 28, having passed thirteen consecutive hours in the saddle. The trail from Kalaieha is 35 miles long, and much more than half of it is over bare lava of the "aa" and "pahoehoe" types. No traveler attempts this trip without carrying horseshoeing implements, for the lava is of such a nature that the hoof of an unshod horse would be cut through in a few minutes, and nothing could induce the animal in that case to continue the journey. We saw the carcasses of a dozen horses that had been mercifully killed or unmercifully left to die of starvation.

Cocoanut Island was occupied at Hilo from July 30 to August 3, and we arrived in Honolulu on August 6. At the request of Prof. Alexander, the Surveyor-general of the Kingdom, I left on the next steamer for Kealakeakua Bay to re-occupy the magnetic station of Capt. Cook at Napoopoo. His observations were made more than one hundred years ago, and were finished just before the outbreak which cost the great discoverer his life. On the way back to Honolulu I stopped three days at Lahaina, and made magnetic observations where De Freycinet had an observatory in 1819. Honolulu was again reached on August 27. Two more stations remained to be occupied, and on August 30 we left for Kauai. The work being done at Waimea I went on board the *Mikahala.* Learning that before returning to Honolulu she would go to Niihau I determined to make the trip and get one station on that seldom visited island. This neither increased the expense nor delayed my return, as otherwise it would have been necessary to wait at Waimea until the vessel came back.

IV.—METEOROLOGICAL OBSERVATIONS.

When it was decided to occupy the summit of the highest mountain in Hawaii, the occasion was taken to verify its height, as determined previously by Prof. Alexander. To this end barometers were read at the four mountain stations, Kawaihae, Waimea, Kalaieha, and Waiau. Simultaneously with this, barometric observations were made in Honolulu, and at Hilo and Waimea, on Hawaii. The wet and dry bulb thermometers were also read for the relative humidity, and the direction and force of the wind, the percentage of clouds, etc., were noted. On the summit the mercurial barometer stood at approximately 18·3 inches at a temperature of about 54° F.

On September 14 I took passage in the steamship *Australia* for San Francisco. Arriving on the 21st, I found orders from the Superintendent to measure the force of gravity at the Lick Observatory. This was done between September 28 and October 2, the time between September 22 and 27 being employed in getting the instruments through the custom-house and in repairing the pendulum apparatus, which was considerably out of order from the experiences on the top of Mauna Kea. On October 4 I started for Washington and arrived on the 16th.

In closing, I desire to express my obligations to the Surveyor-general, Prof. W. D. Alexander. Throughout my entire stay I was the constant recipient of professional favors. The observatories at Waikiki, the meridian mark on Makiki, and the transportation of the heavy outfit to the gravity station above the clouds, all bear testimony to his generous aid. It is due to the Hawaiian Government Survey to state that the greater part of the Mauna Kea expenses were borne by that Bureau.

The following table gives a summary of the season's work:

Summary of observations in the Hawaiian Islands in 1891–'92.

Station.	Island.	Date of occupation.	Class of observations.	Nights or days of observations.	No. of determinations.	Remarks.
		1891. 1892.				
Waikiki.	Oahu.	June 6–June 25	Latitude.	220	2434	
		June 9–June 11	Gravity.	199	827	
		June 9–June 11	Time.	202	202	
		1891.				
		Aug. 11–Aug. 13	Magnetic.	3	3	
Kahuku.		Nov. 25–Nov. 27	do.	3	3	
		1892.				
Honolulu.		June 23–June 25	Gravity.	3	57	
		June 15–June 27	Time.	10	10	
		June 2–June 4	Magnetic.	3	3	
Kawaihae.	Hawaii.	July 4–July 6	Latitude.	3	23	
		July 3–July 6	Gravity.	4	91	
		July 3–July 6	Time.	4	4	
		July 1–July 3	Magnetic.	3	3	
		June 30–July 7	Meteorology.	8		
Waimea.		July 8	Magnetic.	1	1	West base.
		July 9–July 11	do.	2	2	Old station.
		July 7–July 11	Meteorology.	5		
Kalaieha.		July 14–July 15	Latitude.	2	3	
		July 14–July 16	Gravity.	3	67	
		July 14–July 18	Time.	6	6	
		July 14–July 16	Magnetic.	3	3	
		July 13–July 18	Meteorology.	6		
Waiau.		July 21–July 25	Latitude.	4	55	
		July 22–July 25	Gravity.	4	81	
		July 21–July 25	Time.	4	4	
		July 21–July 24	Magnetic.	3	3	
		July 21–July 26	Meteorology.	6		
Hilo.		July 30–Aug. 3	Magnetic.	5	3	
Napoopoo.		Aug. 18–Aug. 21	do.	4	3	
Lahaina.	Maui.	Aug. 23–Aug. 25	do.	3	3	
Waimea.	Kauai.	Sept. 2–Sept. 3	do.	2	2	Latitude station, 1887, and transit of Venus, 1874.
		Sept. 5–Sept. 6	do.	2	2	Thorny Croft.
Nonopapa.	Niihau.	Sept. 9	do.	1	1	

In the column "Number of determinations," the figures indicate:

For latitude.—The number of pairs of stars.

For gravity.—The number of intervals, each giving one value for the period of oscillation of the pendulum.

For time.—The number of sets of stars, each one giving a correction to the chronometer.

For magnetic.—The number of determinations of all three elements—declination of the needle, the dip and the horizontal intensity, and time and azimuth.

The meteorological observations were made many times during the day. The barometer was read at the times of maximum and minimum, at 9 a. m. and 3 and 9 p. m. On the summit of Mauna Kea it was read more frequently.